Landfill Gas Generation at Open Dump Landfills in Developing Countries

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Background Information

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Global Methane Emissions from Solid Waste Disposal Facilities

Country	Emissions ($MtCO_2$ eq)	Population	lbs CO_2 eq/ person
United States	130.6	298,444,215	875
China	46	1,313,973,713	70
Mexico	33.3	107,449,525	620
Canada	25.3	33,098,932	1,529
Russian Federation	34.2	142,893,540	479
Saudi Arabia	19.4	27,019,731	1,436
India	15.9	1,095,351,995	29
Brazil	16.6	188,078,227	177
Ukraine	13.4	46,710,816	574
Poland	17.1	38,536,869	887
South Africa	16.8	44,187,637	760
Turkey	10.4	70,413,958	295
Israel	9.7	6,199,008	3,130
Australia	8.7	20,264,082	859
Dem. Rep. of Congo	7.4	62,660,551	236
Rest of the World	342.7	3,029,887,465	226
World Total	**747.5**	**6,525,170,264**	**229**

Emissions in million tons of CO_2 equivalent from MSWLFs

Base Year 2005

Emissions data from EPA, 2006 "Global Mitigation of Non-CO_2 Greenhouse Gases"

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Factors Influencing Methane Generation at Landfills

- Population
- Quantity of waste disposed per capita
- Composition of waste
- Type of waste disposal site

Characterizing Waste Disposal Sites

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Types of Waste Disposal Sites

- Sanitary landfills
- Open dumps
- Managed dumps

Landfill type is depends on the operational controls at the site. The major issue for gas generation is the oxidation potential in the waste. Other factors influence waste composition.

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Features of a Sanitary Landfill

- Base lining and leachate collection system
- Controlled placement of waste
- Mechanical compaction of waste
- Grading and leveling of waste
- Application of cover soil
- Fire control
- Control over scavenging
- Vector control

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Base Lining and Leachate Collection System

- Retains/controls landfill moisture
- Limits migration of LFG
- Improves gas pressure in landfill
- Improves efficiency of LFG collection system

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Lined Disposal Cell, Dominican Republic

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Controlled Placement of Waste

- Limits time of atmospheric exposure
- Limits exposure to scavengers and vectors
- Decreases specific surface of waste

  (S.S. of uncontrolled waste piles 0.4-0.5 ft^2/ft^3, compared to 0.1 to 0.15 ft^2/ft^3 for continuous cell operation)

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Continuous Cell Landfill, Morocco

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Continuous Cell Disposal, Ukraine

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Uncontrolled Waste Site, Egypt

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Loosely Placed Waste, Egypt

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Loosely Placed, Thin Lift of Waste Pakistan

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Loosely Placed Waste, Dominican Republic

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Mechanical Compaction

- Increases density of degradable mass
- Increases LFG pressures by decreasing void space and effective air porosity
- Decreases air permeability (particularly vertical permeability)

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Landfill Compactor, Ukraine

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Application of Cover Soil

- Limits the depth of oxidation in the waste
- Provides a barrier to LFG ventilation
- Provides a barrier to scavengers and vectors
- Improves efficiency of LFG collection system

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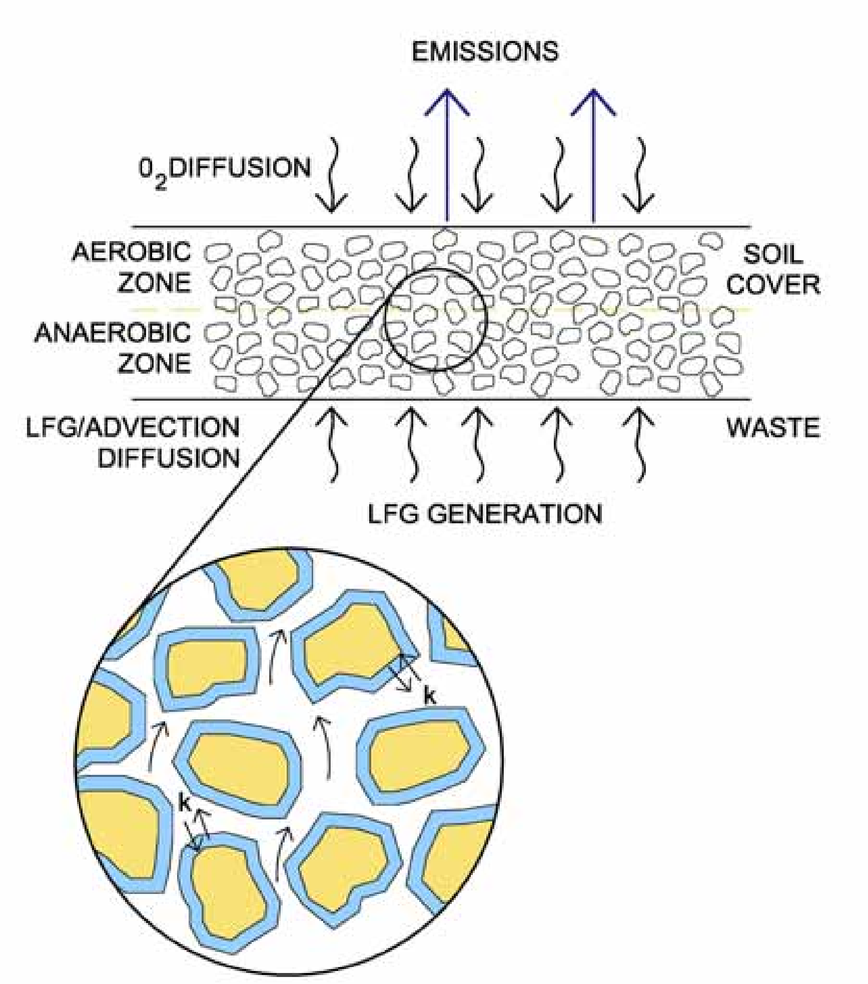
Aerobic Degradation System Within a Soil Cover



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Placement of Cover Soil, Egypt

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Partial Cover at Egyptian Landfill

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Control of Landfill Fires

Issues with landfill fires

- Consume landfill gas
- Reduce degradable fraction of waste (reduction in L_0)
- Introduce O_2 into landfill (reduction in k)
- Remove moisture from landfill (reduction in k)
- Generate smoke, CO, other toxins

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Landfill Fire at a Managed Dump, Ukraine

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Landfill Fire at Managed Dump, Egypt

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Fire Vents in Cover Soil, Egypt

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Effect of Landfill Fire on Gas Pressures

Location	Average difference between atmospheric and subsurface pressure (kpa)	Average Temperature (deg C)
P1-A	-0.0575	21.7
P1-B	-0.0717	21.7
P2-A	-0.080	19.9
P2-B	0.0276	19.9
P3-A	-0.0517	21.1
P3-B	-0.0631	20.7
P4-A	-0.0855	19.6
P5-A	0.0114	29.1
P5-B	-0.0917	29.1

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Control of Scavengers and Vectors

- Minimizes disturbance of waste
- Minimizes the separation of waste
- Maintains degradable carbon in waste

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Seabirds, Egypt

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Wild Dogs, Egypt

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Goats at Egyptian Landfill

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Cattle Feeding, Morocco

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Waste Degradation Products

- Aerobic (oxidation potential >-330 mV)

$$C_6H_{12}O_6 + O_2 \rightarrow CO_2 + H_2O + biomass + heat$$

1kg 0.64kg 0.88kg 0.34kg 0.40kg 9300kJ

- Anaerobic (oxidation potential <-330 mV)

$$C_6H_{12}O_6 \rightarrow CH_4 + CO_2 + biomass + heat$$

1kg 0.25kg 0.69kg 0.056kg 632kJ

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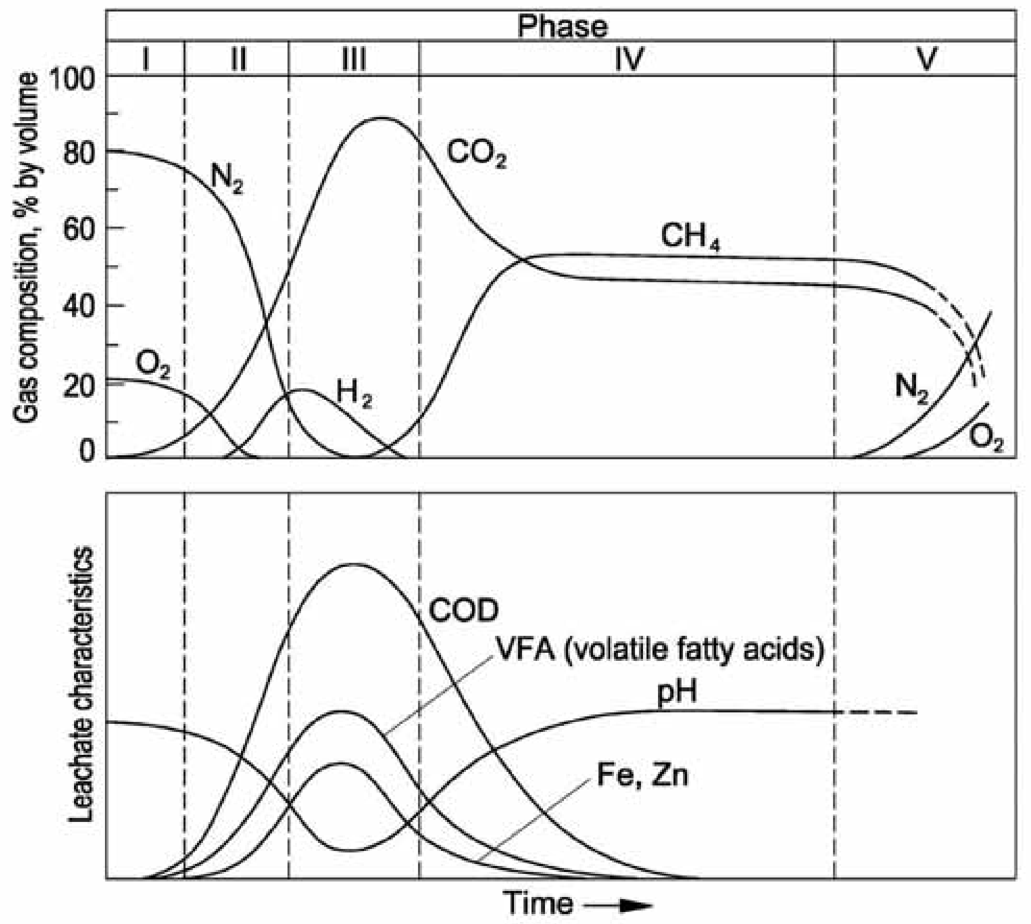
Landfill Gas Generation Life Cycle



Generalized phases in the generation of landfill gases (I = initial adjustment, II = transition phase, III = acid phase, IV = methane fermentation, and V = maturation phase).

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Highly Oxidized Waste

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Characteristics of Oxidized Waste, Ukraine

Sample Number	Depth (m)	Water (%)	Ash (%)	Organic Matter (%)	Degradable Carbon (%)
1	4.5	29.3	87.5	12.5	4.7
2	7.5	35.0	90.5	9.5	3.6
3	10.5	24.7	87.9	12.1	4.5
4	6.0	38.3	83.2	16.8	6.3
5	6.5	26.7	84.7	15.3	5.8
6	6.5	42.3	81.4	18.6	7.0
7	6.0	37.3	83.9	16.1	6.0

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Estimating Landfill Gas Generation

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Three Approaches for Preliminary Gas Generation Potential Evaluation

- Theoretical Gas Yield Methodology
- IPCC Default Methodology
- First Order Kinetics Methodology

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Theoretical Gas Yield Methodology

Simplest method for estimating methane emissions from a landfill. Assumes that all potential methane generation is released from waste in the year of disposal.

EPA rule of thumb: 200 ft^3 of LFG/ton of waste in place.

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IPCC Default Methodology

$$Q = [(M_T)(LF_f)(MCF)(DOC)(DOC_F)(F)(4/3) - R] \times (1 - OX)$$

M_T=Total waste generated

LF_f=Fraction of waste disposed of at landfill

MCF=Methane Correction Factor

DOC=Degradable Organic Carbon

DOC_F=Fraction DOC dissimilated

F=Fraction of CH_4 in LFG (0.5)

R=Recovered CH_4

OX=Oxidation Factor

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IPCC Methane Correction Factors

Sanitary or Managed Landfill	MCF=1.0
Open Dump (>5m waste)	MCF=0.8
Open Dump (<5m waste)	MCF=0.4
Default (uncategorized LF)	MCF=0.6

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Theoretical First Order Kinetics Methodology

- EPA LandGem Model (first-order decay equation)

$$Q = 2kL_o \sum_{i=1}^{n} M_i e^{-kt_i}$$

K: Decay rate. Function of moisture content, availability of microbial nutrients, pH, Temperature

L_o : Methane generation potential. Function of cellulose content.

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EPA Suggested Values for k and L_0

Variable	Range	Wet Climate	Medium Climate	Dry Climate
L_0 (M^3/Mg)	140-180	140-180	140-180	140-180
K (1/yr)	0.003-0.4	0.1-0.35	0.05-0.15	0.02-0.10

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Values used for regulatory compliance in the United States

- Clean Air Act
  - $L_0 = 170\ m^3/Mg$
  - $k = 0.05\ 1/yr$

- AP-42 (NMOC emissions estimates)
  - $L_0 = 100\ m^3/Mg$
  - $k = 0.04\ 1/yr$

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Baro-Pneumatic Method for Estimating LFG Generation Rate

- Collect pressure and flow data from the landfill
- Determine porosity and horizontal permeability from pump test data
- Determine vertical permeability by comparison of landfill pressures with atmospheric pressures using Darcy's Law/Continuity Equation
- Determine gas generation using standard principles of gas flow, comparing transformed landfill pressures to atmospheric pressure
- Numerically analyze age/gas generation data to calibrate first-order decay constants

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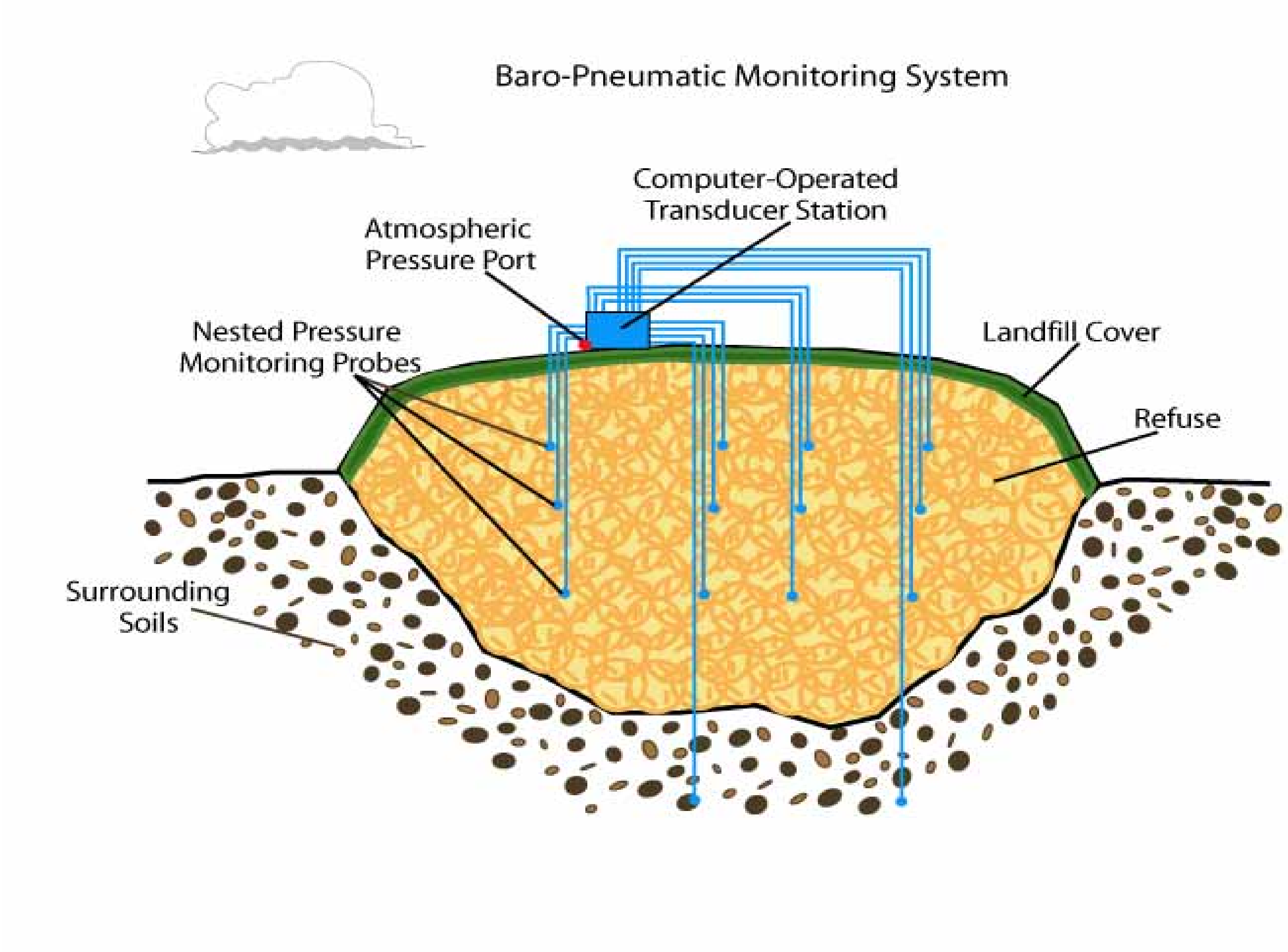
Pressure and Flow Data



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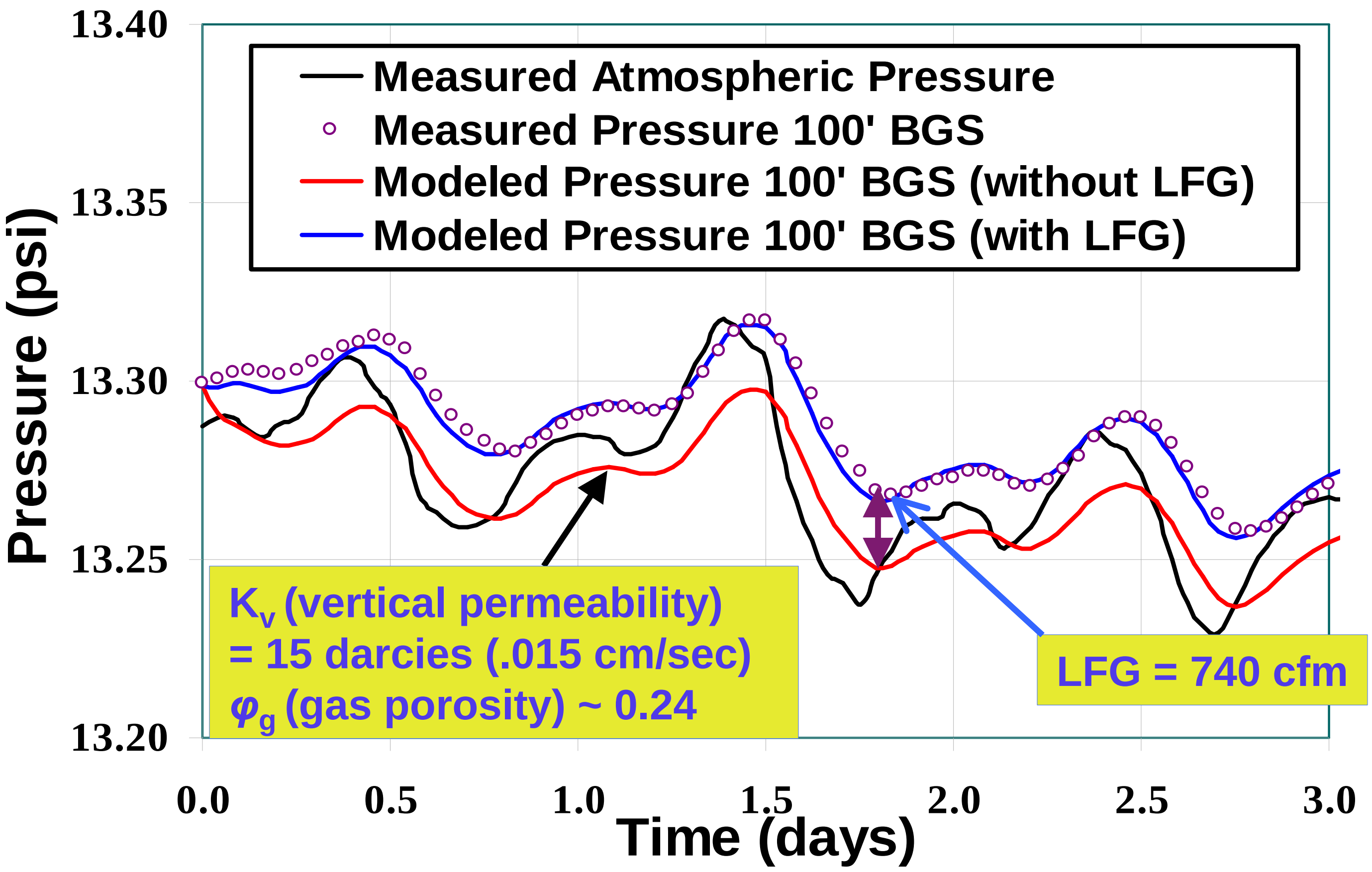

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Basic Screening Criteria

- Minimum of one million tons of waste in place
- Landfill is actively receiving waste, or has been closed for no more than a few years
- Landfill depth of at least 30 feet
- Sanitary landfill or managed dump operating practices

Should also consider climate, waste type, and waste condition.

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